A STUDY OF THE EFFECT OF TREE LEAVES ON WIND MOVEMENT*

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ABSTRACT

Using wind data observed in the micro-meteorological portion of the Nashville Community Air Pollution Network, a study is made of wind flow near deciduous trees during periods of foliation and defoliation. This difference in wind flow is contrasted with wind patterns in treeless or nearly treeless environments. It is concluded that in an area of numerous but well-spaced mature deciduous trees, the wind is about 25–40 percent greater during periods of defoliation.

1. INTRODUCTION

Trees have been used for protection from the wind for ages past. Numerous quantitative measurements of this protection have been calculated by use of speed measurements on the windward and lee sides of windbreaks. Little attention, however, has been paid to what portion of this measure of protection is due to leaves on deciduous trees. This study attempts to develop a measure of the contrast of wind speeds through deciduous trees during periods of foliation and defoliation.

The U.S. Public Health Service operated a network of air sampling stations in Nashville, Tenn., during the period from August 1, 1958, to July 31, 1959 [1]. This network consisted of 119 stations in the urban area and four rural control stations. The urban stations were located by a grid pattern centered roughly on a point just behind the Federal Building in downtown Nashville. A rural control station was located in each of the cardinal compass points approximately 8 miles from the center station of the grid. In addition to the various air sampling instruments located at each of the stations, 32 of the urban stations were equipped with anemometer/odometer instruments to record 24-hour wind movement. The anemometers were mounted on utility poles between 30 and 35 feet above ground. These 32 wind observing sites were randomly selected to approximate a grid-within-a-grid pattern (fig. 1) and consequently represented a sampling of various environmental factors. The random sampling process so desirable in this type of survey naturally resulted in some anemometers being placed in wooded sections of town with a small number of instruments located within a few hundred feet of numerous trees. A study of wind movement by seasons at these "tree-influenced" stations contrasted with wind movement at other stations in the network presents an opportunity to evaluate the effect of tree leaves on wind.

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2. METHOD OF ANALYSIS

Monthly averages of 24-hour wind movement were computed for each station and month for which reasonably complete data are available. These monthly average station values were then combined to yield a monthly average 24-hour wind movement for the network (fig. 2). As would be expected, monthly average wind speed during the colder months of the year is greater than during the warmer months for the network as a whole. This increase is about 34 miles per day between October and November and corresponds with the normal climatological expectancy [2] which shows an increase in average hourly wind speed from 5.2 m.p.h. in October to 7.7 m.p.h. in November.

A ratio of station monthly average speed to network monthly average speed and to Weather Bureau Airport Station (WBAS) monthly average speed was computed for each station-month. Results of the two computations were quite similar due to the high correlation between network and airport wind observations. Since the WBAS winds are generally considered to be standard for the area, the ratio of station monthly average wind speed to WBAS monthly average wind speed, expressed as a percentage, has been adopted as the basis for this analysis. Hereafter, for sake of brevity, this ratio will be referred to as S/A—station to airport ratio. The computed values of S/A are tabulated in table 1.

Changes in S/A for individual successive months at a station are often difficult to explain and might be due to a great variety of influences. Therefore, an average S/A for homogeneous seasons was thought to be possibly more meaningful. Accordingly, an average S/A for the 3-month period of August, September, and October was calculated to represent the period when deciduous trees are foliated and will be referred to as $(S/A)_{Summer}$. The December, January, and February average was selected to represent the period of defoliation and will be referred to as $(S/A)_{Winter}$. This selection of months is based on

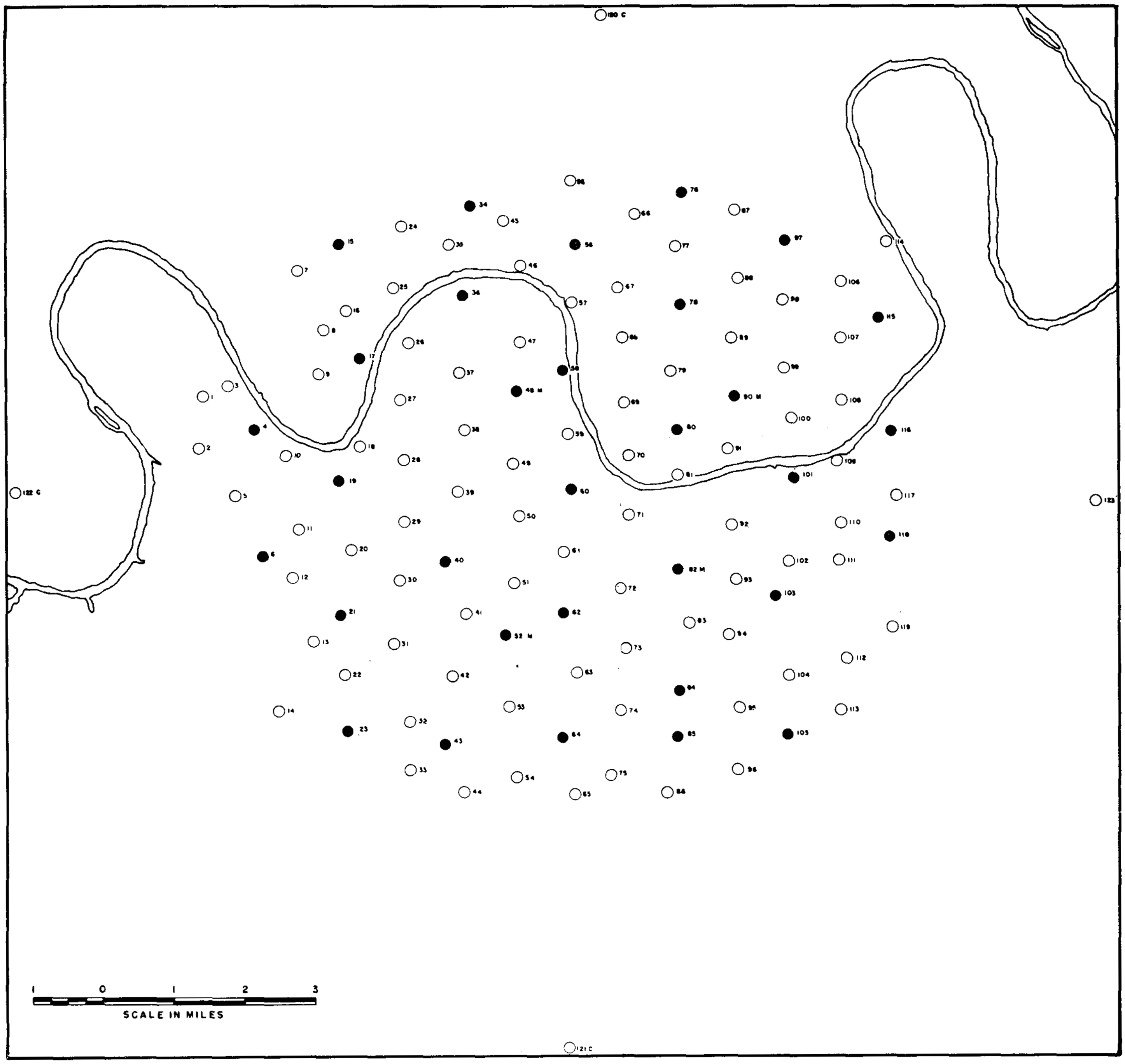

FIGURE 1.—Sampling station network, Nashville Community Air Pollution Study. Solid circles show anemometer/odometer sites.

information obtained by Dickson [3] from the Tennessee Division of Forestry which advised that defoliation in the vicinity of Nashville begins at or before the time of the first fall freeze (normally November 7 at Nashville) with most of the leaves down by about mid-November. Leaf emergence normally begins in early March but is highly variable depending upon the weather. Thus the months selected contain little or no transition period and should truly represent the physical qualities selected for study.

A second ratio has been formed for each station. This will be referred to as W/S and is formed by dividing $100 \times (S/A)_{\mathrm{Winter}}$ by $(S/A)_{\mathrm{Summer}}$. Table 2 lists, for the 30 stations that have acceptable records for the period studied, the following: Average 24-hour wind movement, August-October (col. 1) and December-February (col. 2); average ratio $(S/A)_{\mathrm{Summer}}$ (col. 3); average ratio $(S/A)_{\mathrm{Winter}}$ (col. 4); ratio W/S (col. 5).

In all cases the ratio W/S is greater than 100 indicating that $(S/A)_{\mathrm{Winter}}$ is always higher than $(S/A)_{\mathrm{Summer}}$. One reason for this is the character of the instruments being compared. The WBAS anemometer is more sen-

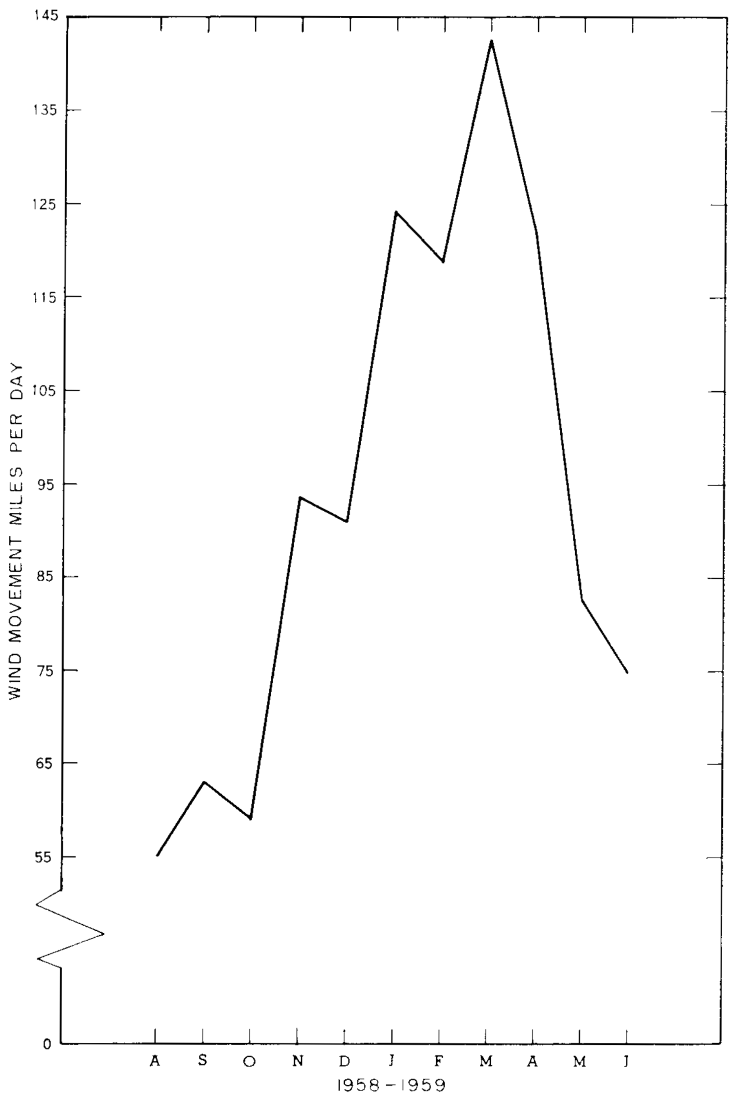

Figure 2.—Monthly average 24-hour wind movement at stations of Nashville Community Air Pollution Network, August 1958 through June 1959.

sitive and has a lower starting speed than the survey instruments. Thus in summer, with its greater proportion of light winds, the survey instruments measure a smaller percentage of actual winds than they do in winter. A second reason is that the stronger winds are less stable and have greater ability to penetrate the jungle of buildings that make up an urban area and thus bring wind measurements in this urban complex into better agreement with the well-exposed and relatively open airport location. Those arguments not only explain the increase of S/A in winter but also explain the fact that WBAS daily winds are consistently higher than those measured by the survey network.

It would be more conclusive to this study for data following spring emergence likewise to be contrasted with the winter data. Unfortunately much data were lost after February because of an increasing frequency of equipment failure. Three of the test stations are missing or incomplete following February. The results at the remaining stations are generally as expected but the distinction between "tree-influenced" and other stations is not so clear-cut as during the fall period of defoliation. This is thought to be because the emergence of the leaves and their growth to maturity is a more gradual process

Table 1.—*Monthly average values of S/A for stations in the Nashville Community Air Pollution Wind Network, August 1958–June 1959*

Station No.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June
4	48.5	50.1	52.6	55.1	58.7	62.9	62.5	65.5	55.0		52.0
15	56.6	61.6	59.7	60.1	55.8	62.1	67.2		66.3	61.4	58.2
17	48.3	45.0	50.2	57.8	52.6	61.5	59.5	70.0	62.7	52.7	51.5
19	57.7	60.5	60.8	64.3	59.8	66.8	67.9	73.3	67.6	60.5	58.9
21	22.8	26.0	24.8	37.2	35.0	39.6	39.4				
23	36.5	40.7	37.3	52.5	52.6	56.1	57.5	58.0	52.7	45.7	43.8
34	48.3	47.6	49.1	52.0	51.8	57.1	57.3				
36	51.2	54.3	52.7	57.7	49.8	59.8	60.6	69.6	64.8	58.7	57.9
40	23.8	24.3	23.9	26.5	31.1	33.9	33.8	32.5	29.1	26.5	23.5
43	43.6	46.9	42.5	54.3	50.6	55.4	60.8	66.7	60.7	55.6	
48	44.4	45.1	41.7	41.7	46.3	46.6	47.7	48.3	44.3	42.2	
52	54.4	55.4	59.5	56.6	57.4	56.1	56.8	57.2	54.5	52.4	52.2
56	48.4	55.1	54.5	55.2	54.7	57.1	57.6	65.0	49.1		
58	46.3	46.6	43.7	46.5	43.3	51.9	54.5	59.9	56.6	56.4	54.8
62	29.9	26.7	30.8	34.2	39.0	38.2	37.9	39.2	33.3	26.4	26.0
64	36.9	35.0	33.3	49.4	51.4	54.9	57.6	57.7	52.9	41.6	
76	45.8	50.1	45.5	49.8	48.4	52.8	58.1				
78	29.9	32.0	33.7	36.0	37.3	41.0	44.4	47.5	44.3	31.9	31.5
80	31.2	34.7	32.4	35.1	37.9	38.4	40.8	45.3	39.2	34.1	40.2
82	53.7	55.2	63.0	65.8	63.7	68.5	70.2	68.5	67.8	56.3	52.6
84	51.9	54.4	52.9	61.1	59.6	69.4	69.0	70.4	61.3	54.4	52.2
85	63.6	69.1	63.0	69.4	67.4	77.6	77.6	78.4	75.7	76.1	69.7
90	32.8	33.1	36.1	36.6	38.9	39.1	43.3	46.0	43.6	34.0	32.3
97	23.2	20.5	27.9	32.9	35.6	36.0	39.4	39.7	33.9	22.7	25.4
101	25.5	25.1	23.9	32.3	31.0	36.0	37.1	37.7	34.3	24.8	20.6
103	50.2	55.2	53.3	59.2	55.9	62.9	65.2	68.4	66.9	56.0	55.6
105	42.0	40.2	51.5	61.8	59.0	63.6	70.4	67.5			51.7
115	40.4	36.5	43.3	52.2	54.7	59.6	61.7	62.0	59.4	47.6	42.8
116	51.9	60.7	56.1	64.0	61.3	66.6	66.1	72.4	67.9	63.9	60.8
118	48.6	49.4	51.9	53.7	59.9	61.4	66.1	63.6	57.5	42.7	41.9

Table 2.—*Average 24-hour wind movement $\overline{V}$, average ratio S/A, and ratio W/S at stations of Nashville Community Air Pollution Wind Network*

Station No.	(1) $\overline{V}$ (Aug.-Oct.)	(2) $\overline{V}$ (Dec.-Feb.)	(3) $(S/A)_{summer}$ (Aug.-Oct.)	(4) $(S/A)_{winter}$ (Dec.-Feb.)	(5) W/S $\left(\frac{100 \text{ col. } 4}{\text{col. } 3}\right)$
4	67.4	127.5	50.4	61.4	122
15	79.3	128.3	59.3	61.7	104
17	63.8	120.7	47.8	57.9	121
19	79.8	134.9	59.7	64.8	109
21	32.8	79.2	24.5	38.0	155
23	51.1	115.1	38.2	55.4	145
34	64.8	115.3	48.3	55.4	115
36	70.5	118.4	52.7	56.7	108
40	32.1	68.5	24.0	32.9	137
43	59.3	115.7	44.3	55.6	126
48	58.4	97.1	43.7	46.9	107
52	75.4	117.6	56.4	56.8	101
56	70.5	117.2	52.7	56.5	107
58	60.9	104.1	45.5	49.9	110
62	38.8	79.4	29.1	38.4	132
64	46.8	113.5	35.1	54.6	156
76	63.0	110.5	47.1	53.1	113
78	42.6	85.1	31.9	40.9	128
80	42.9	81.0	32.8	39.0	119
82	76.5	140.2	57.3	67.5	118
84	71.0	137.6	53.1	66.0	124
85	87.3	154.6	65.2	74.2	114
90	45.4	83.9	34.0	40.4	119
97	31.8	76.7	23.9	37.0	155
101	33.2	72.3	24.8	34.7	140
103	70.8	127.7	52.9	61.3	116
105	59.4	133.8	44.6	64.3	144
115	53.4	122.0	40.1	58.7	146
116	75.4	134.4	56.2	64.7	115
118	66.7	129.6	50.0	62.5	125
Mean	59.04	111.4			

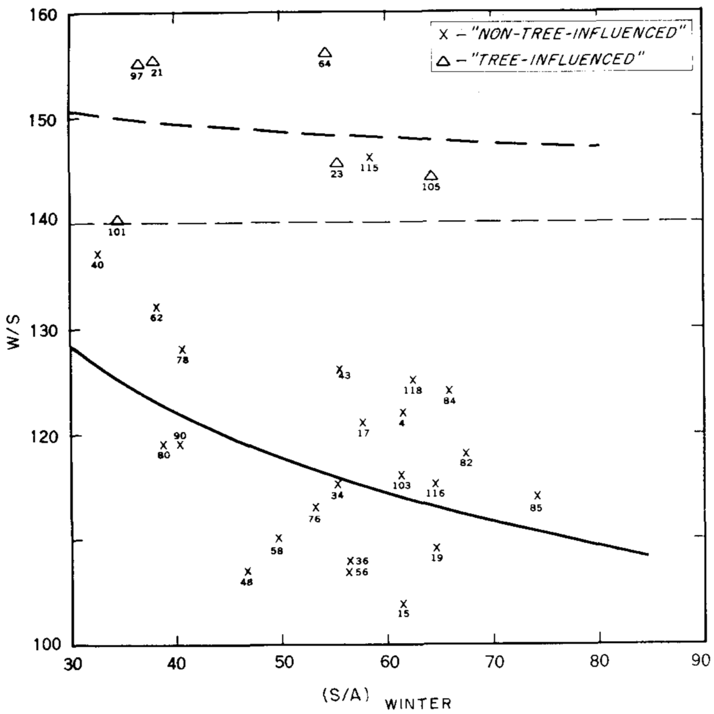

Figure 3.—Scatter diagram of W/S vs $(S/A)_{\text{winter}}$. The solid line is fitted to values for the "non-tree-influenced" stations and the heavy dashed line to values for the "tree-influenced" stations.

than is the defoliation process of fall. In discussing individual stations, the spring data are presented where available.

3. STUDY OF DATA

It will be noted in table 2 and figure 3 that there are seven network stations which show W/S values of 140 or higher. A study [4] of the environment of these stations shows that six are influenced by trees within a radius of a few hundred feet. These six stations have been labeled "tree-influenced" since no other physical reason can be found for their significantly higher W/S. Additional inspection shows that other stations having W/S above network average (122.3) but below 140 also have some trees in the vicinity but the narrative descriptions of the stations indicate that the trees are at greater distances, lower heights, and/or more widely scattered than at the so-called "tree-influenced" stations.

A mean $\overline{W/S}$ for the "tree-influenced" stations was formed and a second mean $\overline{W/S}$ was formed for the remaining stations (those considered non-tree-influenced). Through the use of an F variance ratio test and a t test, it was statistically shown that the two means do not, at the 0.95 confidence level, come from the same population. Since tree influence was the determining characteristic, with no consideration given to geographic location, topographic exposure, or other factors in selecting the two groupings of stations (making up the mean $\overline{W/S}$), it is suggested that the factor leading to the measured population difference in $\overline{W/S}$ is the presence or absence of trees in the immediate vicinity of the reporting stations.

It was mentioned that seven stations report W/S of 140 or higher but only six are considered "tree-influenced." No such influence can be found at the seventh (115). Station 115 is located in a new residential area with only scattered trees, few of which are as high as the instrument. It is possible that the increase (or part of it) is due to the terrain which slopes away from the site in the north and west directions with a slight rise toward the east and south. Thus, while the station is protected from the prevailing southerly winds of the warmer seasons, it is not protected from the more frequent and stronger westerly and northerly winds of winter. An alternate explanation that appears possible is that, in this area of new housing, land clearing activity in the fall may have altered the wind pattern.

Figure 3 is a scatter diagram of a part-whole correlation* with $(S/A)_{\text{winter}}$ as abscissa and (W/S) ratio as ordinate. The diagram shows that the increased S/A in winter is greater at stations with lower average speed and this does not appear to be a linear function. The top (dashed) regression line is empirically fitted to the data from the six "tree-influenced" stations. The lower (solid) regression line is fitted to the 23 "non-tree-influenced" stations. The interesting feature of the diagram is how clearly the "tree-influenced" stations stand apart from the remainder of the network to illustrate that some influence is present at these particular stations which causes their winter S/A to increase to a far greater extent than the remainder of the data would lead us to expect. Once again it is suggested that this influence is the presence of deciduous trees.

4. DISCUSSIONS OF INDIVIDUAL "TREE-INFLUENCED" STATIONS

Site 21.—The anemometer is in an older residential neighborhood located in a shallow valley. There is a gentle rise toward all directions but the southwest. The area is wooded with trees in most directions, at various heights and distances, and there are few openings in the tree barrier. Some 35- to 40-ft. trees are within 100 ft. of the anemometer to the northeast and east. Within a 300-ft. circle there are trees of 50 ft. or higher. The greatest concentration of trees appears to be to the west of the instrument. The W/S ratio at this station was 155. The acceptable record for this station ended in February so no conclusions can be made about the period after spring foliation.

Site 23.—The anemometer is in a well-established residential neighborhood (fig. 4). The environment is heavy with trees and vegetation. This part of town is a series of rises, knolls, and small hills. The anemometer site is on top of one such rise. Most of the trees within 100 ft. of the instrument appear lower than the exposure height but many higher trees are situated between 100 and 300 ft. distant. The W/S ratio at this station was 145. During

*The term plotted as abscissa also appears as a portion of the ordinate term. In other words $(S/A)_{\text{winter}}$ appears in both ordinate and abscissa and thus the diagram contrasts one variable with itself plus an arithmetic combination of itself and some other term.

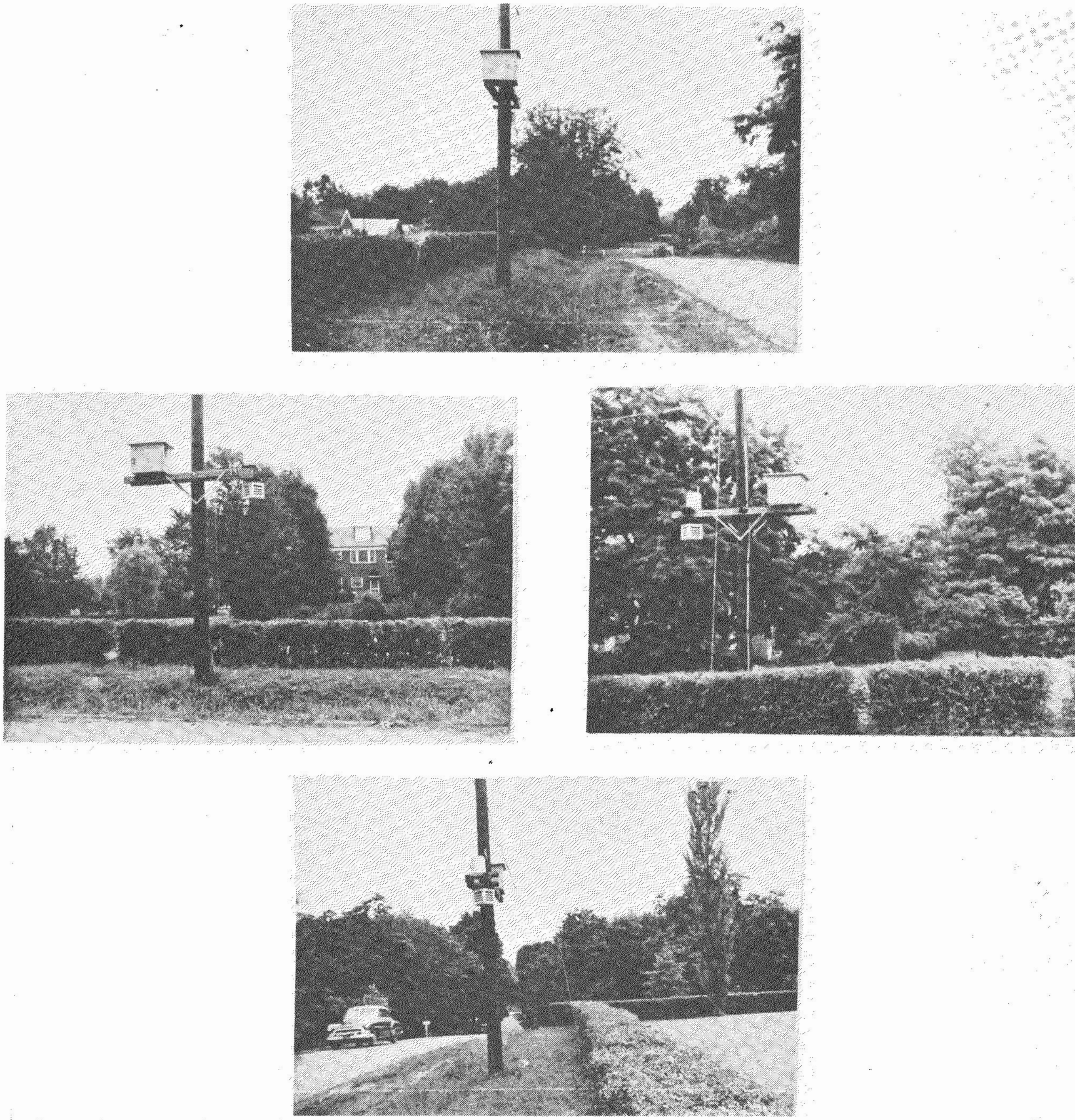

Figure 4.—Site 23, a typical "tree-influenced" station. Anemometer is located atop the utility pole. Starting at top and moving clockwise pictures are taken looking north, east, south, and west on May 30, 1959.

the spring period of leaf emergence the S/A ratio winter to spring was 117. The S/A ratio between winter and spring would not usually be as large as the ratio between winter and late summer-early fall because of the higher wind speeds in spring (as opposed to fall). The 117 value for this station was exceeded by a few "non-tree-influenced" stations, but due to unreliability of much of the spring data this is not accepted as disproving the theory here investigated.

Site 64.—The anemometer is situated in a residential neighborhood composed mostly of ranch type houses. The location is close to the top of a knoll with the greatest down-slope toward the west. There are trees higher than the anemometer about 200 ft. to south-southwest while the east is blocked by trees 300 to 500 ft. away. The S/A increase after leaf fall at this observation point was 19.5 or a W/S ratio of 156. The spring data are incomplete but the record available indicates a trend consistent with the postulation.

Site 97.—A residential neighborhood surrounds this station. The whole section of town is relatively low but in the immediate vicinity of the site there is a gentle down-slope toward the east with a somewhat sharper down-slope starting a short way to the north. There are numer-

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ous trees in the neighborhood with the most pronounced tree-shading of the anemometer from the east, south, and northwest. The 13.1 increase in S/A from the period when trees were in leaf to the period when leaves had fallen does not seem to be as great as at some other stations. However, the W/S ratio was 155. The S/A ratio declined steadily as the leaves emerged in spring and the average S/A for winter was 136 percent of the average S/A for April, May, and June.

Site 101.—The anemometer is located near the bank of the Cumberland River in front of the filter house at the Nashville Water Works and Pumping Station. This is one of the lowest parts of town and the terrain rises in all directions except toward the river. The instrument is located in the midst of a group of trees and is also shaded by a large building immediately to its south and by rising terrain in most directions. With all these obstructions it is, of course, one of the least windy exposures. The fact that the W/S ratio was only 140 is probably explained by the fact that the many other obstructions diminish the wind before the trees can affect it. The S/A ratio in the spring declined steadily as the leaves emerged and developed and the winter S/A divided by the average from April through June was 130.

Site 105.—The anemometer is located near the top of a hill in a residential neighborhood. There are a number of trees in the vicinity with the highest trees in the southwest and west and also in the eastern quadrant. A study of the S/A reveals about the same pattern as at the other "tree-influenced" stations. The W/S ratio was 144. The record is missing at this station for April and May and there is some question of the validity of the June record.

5. EXAMPLES OF S/A AT "NON-TREE-INFLUENCED" STATIONS

Station 36.—This is an excellent example of an anemometer completely without tree influence in its vicinity. This site is located on a small airport with only a few trees some 600 ft. to the north. The August, September, and October average S/A contrasted with average S/A during the winter months was 108. Site 36 showed a rise of S/A in the spring and finally reached a ratio higher than its fall value.

Station 85.—The anemometer is located in a light industrial area of well-spaced one-story office and warehouse buildings (all lower than the instrument). There are no trees close to the site. Here the ratio rose 9 units during the winter yet the ratio between winter and late summer-early fall was only 114.

Stations 19 and 56.—Both stations had an S/A increase of about 5 units and ratio of less than 110. Once again narrative descriptions of each station make note of the lack of tree influence.

The pattern was generally consistent with low W/S ratios at well-exposed locations and higher values at stations in and near trees. At times, however, the spring trend was confused. This spring trend was seldom contrary to the conclusions here drawn but it did show differences in magnitude.

6. CONCLUSION

An average W/S ratio for the 23 stations considered to be "non-tree-influenced" was 122.3. The average for the six "tree-influenced" stations was 149.2. The difference is statistically significant. It is therefore concluded that in an area of numerous but well-spaced mature deciduous trees or clumps of trees (such as a well-established residential neighborhood), after defoliation the wind increases by a factor near 25 percent over "average exposure" and as much as 40 percent over exposures nearly devoid of trees, and slowly decreases by the same amount as the leaves emerge and mature. These values agree quite closely (considering the differences in variables) with those found by M. Toperczer [5] in Vienna. Values vary somewhat according to number of trees, tree height, and tree distances. It is suggested that an approximate mathematical expression of leaf effect upon wind movement could be developed. However, this would require a specially designed network with accurately measured variables (tree height, density, and distances).

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